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論 文
Articles

Soil Erosion Assessment Using USLE in East Shewa, Ethiopia

By

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Summary : Landscape degradation by soil erosion has increased considerably in Ethiopian lands due to deforestation of natural mountain forests and the cultivation of large areas, resulting in a serious threat to the Ethiopian population. In fact, soil erosion and nutrient depletion, drought and famine have frequently occurred in Ethiopia. Most of the productive topsoil has been degraded, resulting in chronic food shortage and persistent poverty. Soil erosion is a major environmental problem threatening the sustainability of agriculture. The purpose of this study is to establish spatial information of soil erosion risk at East Shewa Zone, Oromia Region in Ethiopia by conducting the integration of the Universal Soil Loss Equation (USLE) using Geographic Information System. Precipitation, topographic, soil data, and land use data were obtained from USGS records and from Ethiopian governmental offices and put into a spatial database using GIS. The factors that influence soil erosion are rainfall erosivitiy (R) obtained from the precipitation database, soil erodibility (K) obtained from the soil database, slope length and steepness (LS) obtained from the topographic database, while crop and management (C) and conservation supporting practices (P) were obtained from the land use database. The erosion analysis through USLE applied on GIS show that most of the lands is East Shewa zone (82%) are under high, very high, severe or very severe erosion and are covered mainly by cultivation, shrublands and grasslands. These lands essentially prone to erosion are located mostly in the north-east, center and south-west of the study area. This study presents the evidence for erosive areas repeatedly cultivated or frequently suggested for grazing such as shrublands and grasslands as is the case of most areas in East Shewa.

Key words : Soil erosion, Land cover, GIS, USLE, Ethiopia

1. Introduction

According to FAO (2003), the average annual agricultural growth rate in Ethiopia is 2.4%, while the average annual population growth rate is 3.2%. This shows the agricultural deficit and explains the problem of poverty in Ethiopia. Decrease in agricultural productivity is due to many reasons : frequent drought and also land degradation. In fact, land degradation is a serious threat for the environment and socio economic situation for rural population in many countries in the world and particularly in Ethiopia.

The undulating topography and heavy rainfall make land vulnerable to degradation. The latter is exacerbated by population pressures that have led to farming new marginal areas not suited to agriculture. In Ethiopia, cultivation on steep slopes and clearing of vegetation has accelerated erosion in the highlands (BHAN 1988).

ADEMOLA *et al.* (2008) reported that Ethiopia loses over 1.5 billion tons of topsoil per year by erosion. However, Ethiopia's economy is mainly based on small-scale agriculture, which represents the principal engine of economic growth.

Accounting for half of the GDP, the agriculture sector employs 85% of the labor force (SHIFERAW and HOLDEN,

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1999).

In East Shewa in Ethiopia, the farmers are producing for subsistence and facing an increasing erosion of the land. In fact, to satisfy their needs in food they are ploughing in marginal areas at slope lands. They cut trees in mountains and cultivate cultural vegetation.

Nevertheless, soil and water resources degradation advanced by natural and anthropologic activities are usually controlled by soil conservation techniques and water harvesting constructions. Soil erosion can be limited with proper management of vegetation, plant residue and tillage (LEE, 2004). That is why it is useful to assess physically and then estimate financially the advantage that can be procured by conservation practices in increasing the farmer's benefits and preventing erosion, in zones under desertification threat. It is important to demonstrate and explain how environment degradation could lead to socioeconomic deficiency.

Therefore, it is essential first to establish a GIS (geographic information system) method for spatial distribution of soil erosion, based on the USLE (Universal Soil Loss Equation). Thus, areas suffering from soil erosion were assessed and mapped. This represents the objective of the current article focusing on all East Shewa zone. GIS provided detailed and accurate land data information which contributes to improving statistical and up-dated analysis results of area frame study. In fact, GIS provides national institutions with a standardized and multi-purpose product useful for several environmental and agricultural purposes. Furthermore USLE is an erosion model and one of the most widely used methods for predicting soil loss that would result from splash, sheet, and rill erosion occurring in agricultural plots.

2. Methodology

(1) Study Site overview

In this research, we carried out a field survey of East Showa zone in center Ethiopia, including part of Oromiya Region (Fig. 1). The study area is about 12,248.6 km^2. According to FAO (2003), annual average temperature ranges from 20 to 28℃. Average annual precipitation ranges from 600 to 900 mm. The topography of the area represents elevations ranging from 1,500 to 2,400 m a.s.l. The landscape of the study area is harshly undulating with sparse vegetation and highly covered with stones. In fact East Shewa Zone is located at the Great Rift Valley. The agricultural productions are mainly teff, barley, sorghum maize, café, haricot beans, fruit trees such as mango, papaya, etc. The major soil types are andosols, lithosols, cambisols, luvisols and fluvisols. A topographic map of East Shewa was used as input map

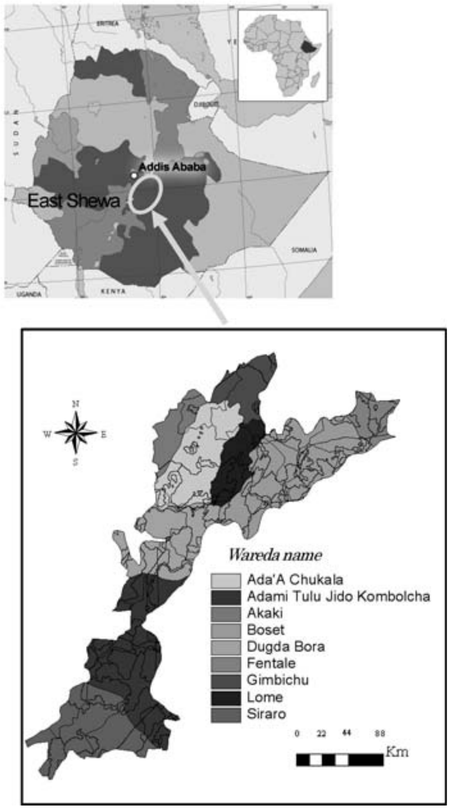

Fig. 1 Location map of the study area of East Shewa

to define the boundaries of the study area. Then, we applied the integration of GIS with USLE Model.

(2) Model Description

Arc GIS 9.2 software was used to integrate data and obtain topographic maps of slope and elevation. In addition, a GIS Arc-View 3.3 Software was used to integrate data and various maps and official censuses of soil, rainfall and land-use obtained from Ethiopian governmental offices records (2005).

USLE (Universal Soil Loss Equation) is a mathematical model used to describe soil erosion processes. The USLE and its derivatives (i.e. RUSLE and MUSLE) are considered as main models used by United States -where it originated- and around the world to measure water erosion. This is why the model has been used for decades for purposes of conservation planning. The USLE is a multiple-factor equation (Eq. 1) in which four non dimensional parameters (L, S, C, P) are used to modify a potential soil loss equal to the product of two dimensional parameters which respectively represent the erosivity of rainfall (R) and the erodibility of a particular soil (K). The USLE has the following form as defined by WISCHMEIER and SMITH (1978) :

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad \text{(Eq. 1)}$$

where :

A : soil loss (t ha^{-1} yr^{-1}),

R : rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1})

K : soil erodibility factor (t h MJ^{-1} mm^{-1})

L : slope length factor (unitless)

S : slope steepness factor (unitless)

C : cover and management factor (unitless)

P : support practice factor (unitless)

The soil erosion distribution map was generated as a product of six vector layers. Each of the USLE factors, with associated attribute data, was digitally encoded in Arc-view 3.3 database to create five thematic layers and obtained 4 maps respectively corresponding to these factors. Then, we made an overlay of these layers using USLE/GIS calculation and we obtained values of soil loss in t ha^{-1} yr^{-1}.

(3) Development of model database for USLE

a) Rainfall erosivity factor (*R*)

Rainfall erosivity is the ability or power of rain to cause soil loss. The R factor is a function of the falling raindrops and the rainfall intensity. The greater the intensity and duration of the rain storm, the higher is the R factor and thus the higher is the erosion potential. Rainfall data were obtained from Ethiopian Ministry of Agriculture (2005).

Renard and Freimund (1994) developed statistical relationships between R factor and both total annual precipitation using a modified Fourier coefficient (F) (Foumier, 1960 ; Amoldus, 1977). The F is calculated as :

$$F=\frac{\sum_{i=1}^{12} P_i^2}{P_a} \qquad \text{(Eq. 2)}$$

Renard and Freimund (1994) recommended to use the equation below when F is greater than 55 mm, R factor is calculated as :

$$R=95.77-6.081F+0.04770F^2 \qquad \text{(Eq. 3)}$$

Where p_i (mm) is average monthly precipitation, P_a (mm) is average annual precipitation.

b) *Soil erodibility factor (K)*

The soil erodibility factor is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The K factor represents the ability of soils to resist erosion and depends on soil texture, structure, and composition. Soil properties were obtained from Ethiopian government data. Then, we corresponded every soil property to the K value referring to Nomograph values calculated by Wischmeier and Smith (1978).

c) Slope length and steepness factor (*LS*)

The slope length factor (L) and slope steepness (S) factors are typically combined together and defined as the topographic factor which is a function of both the slope and length of the land. The topography affects the runoff characteristics and transport processes of sediment on a watershed scale. We obtained the topographic factor *(LS)* which is a function of both the slope steepness (S) and the slope length (L) of the land combined together through ArcView 3.3. We derived the digital elevation model (DEM) data of the study area using the interaction between topography and flow accumulation (Moore and Bruch, 1986). Flow accumulation in a raster-based analysis, is the total number of cells, including non-neighboring cells, that drain into a selected cell (GIS Glossary).

As for the LS factor, they were derived from (DEM) using hydrological modeling which is an extension of ArcView.

The LS factor was calculated as the following equation :

$$LS=\left(\frac{l}{22.1}\right)^m(65.41\sin^2\phi+4.56\sin\phi+0.065) \qquad \text{(Eq 4)}$$

Where l is the slope length (m), Φ is the angle of the slope in degrees, m is an exponent that depends on the slope steepness. m was attributed the value of 0.5 for slopes between 5 and 21% and attributed the value of 0.3 for slopes < 5%.

d) Cover, management and support practices factor (*CP*)

The C factor is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. In fact, crop management factor depends on vegetation cover, which dissipates the kinetic energy of the raindrops before impacting the soil surface. Therefore, vegetation cover and cropping systems have a large influence on runoff and erosion rates. The values of C factors were decided with the use of land cover data described by Wischmeier and Smith (1978).

The C factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled continuous fallow land. The clean tillage consisted of chisel plowing each treatment pasture one time followed by disking two times with a cutting disk to incorporate any plant material and fertilizer and lime into the soil (Bowman *et al.,* 2005).

The conservation practices factor (P) indicates the effects of practices in reducing the volume of water runoff and thus the amount of soil loss. In fact, the P factor represents cropland practice factor and erosion control practices such contouring, strip cropping, terracing, etc. Area with no conservation measures has P

value of 1.0. The *P* factor is defined as the ratio of soil loss with a specific support practice to the corresponding loss with upland and down slope culture. Due to the fact that there were feeble erosion control practices in the research area, the *P* factor was assumed as a unit value ($P=1$).

The cover and management and support practices factors are commonly used to determine the combined land use management factor (the *CP* factor). Data related to the cover management and conservation practices index are derived from USDA (1972) and based on the index value used by Funnpheng *et al.* (1991) ; the *CP* values were adjusted for the study area. The land use/land cover map, obtained from Ethiopian Ministry of Agriculture, was derived from the satellite images and served as a guiding tool in the allocation of the *C* and the *P* factors for different land use classes.

3. Results and discussion

R factor

We obtained the *R* factor values using the digital data. The spatial distribution of the *R* factor is shown in the Fig. 2.

We obtained 5 classes for the rainfall erosivity factor (*R*). We observed that the high value of rainfall erosivity factor ranging from 1,081 to 1,797 MJ mm ha^{-1} h^{-1} yr^{-1} was located in the north east, center and south-east of the study area and is prone to soil erosion.

K factor

The *K* value ranges from 0 to 0.43. The higher *K* value indicates a lower infiltration rate thus the soil is more prone to erosion. The following map (Fig. 3) represents the spatial distribution of the soil erodibility in East Shewa.

We obtained also 5 classes of soil erodibility factor (*K*), the highest ones being located in the north-east, center and south-east of the study site which reflects the most erodible soils, prone to degradation. In fact, in these areas we find silty soils and impermeable subsoils such as clay and soils low in organic matter which are the most susceptible to be eroded (FAO, 2003).

LS factor

We obtained the *LS* factor using the interaction between topography and flow accumulation (Moore and Bruch, 1986). Regarding *S* factor, we create DEM map (Fig. 4) from the elevation data provided by the Ethiopian government. Then from DEM, we derived the *LS* values and created the map corresponding to topography factor (*LS*) (Fig. 5). This latter is classified into 5 classes.

We noted that the lowest *LS* values are located in the

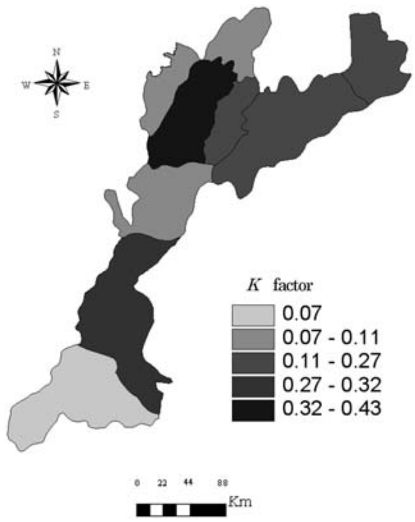

Fig. 3 Spatial distribution of the soil erodibility factor

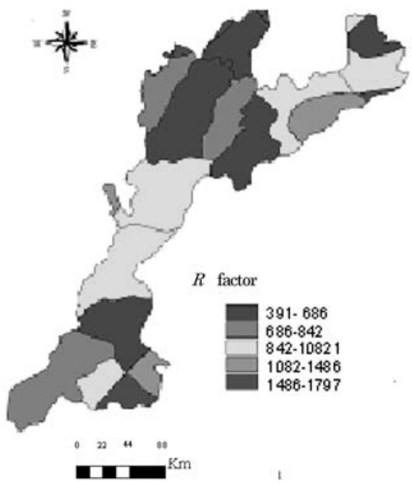

Fig. 2 Spatial distribution of rainfall erosivity factor

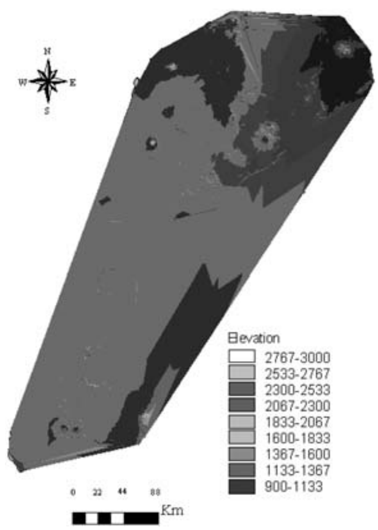

Fig. 4 Digital elvation model of the study area

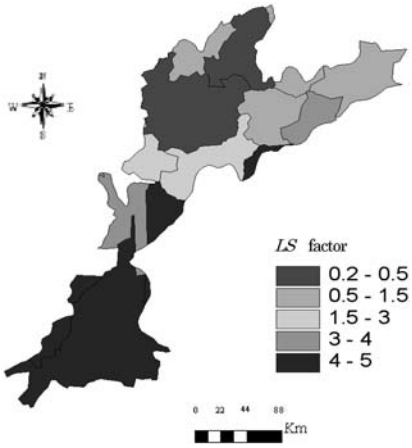

Fig. 5 Spatial distribution of LS factor

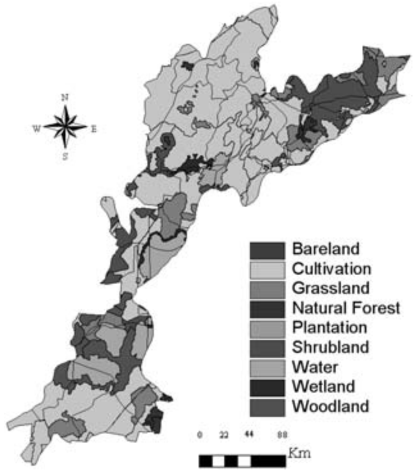

Fig. 7 Land use distribution map

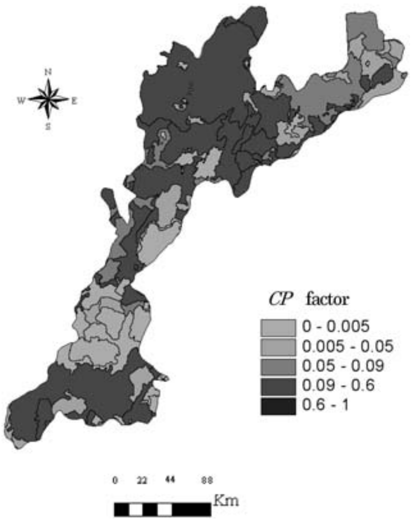

Fig. 6 Spatial distribution of *CP* factor

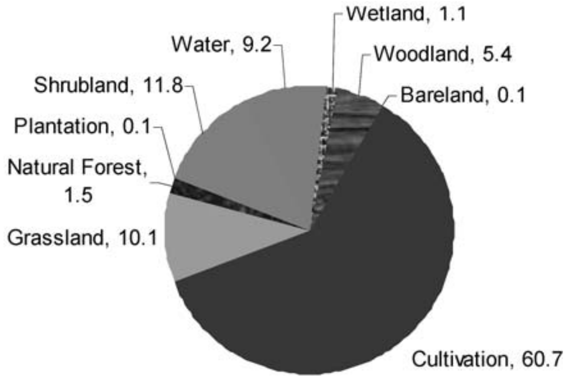

Fig. 8 Area distribution area of land cover in East Shewa (%)

north-west part of East Shewa which reflects that it is less prone zone to erosion.

CP factor

A map of the *CP* (Fig. 6) was generated through reclassification of each land-use/land-cover type into its corresponding *C* values.

Then we generated the land use/land-cover map. This latter shows the existence of nine types of land cover : bareland, cultivation, grassland, natural forest, plantation, shrubland, water, wetland, and woodland.

The distribution map of the *CP* factor and land cover map demonstrate that the zones of high *CP* values ranging from 0.05 to 1 correspond to the most erodable areas covered with cultivation, shrubland and grassland and are distributed randomly all over East Shewa. These types of land cover occupy the largest areas in East Shewa. In fact, cultivation represents 60.7% of the total land-cover in East Shewa zone, followed by shrubland, grassland and water bodies at almost equal percentage of land occupation (11.8%, 10%, and 9.2% respectively). Fig. 8 states this outcome.

Soil loss distribution

The soil erosion map resulting from the spatial overlay of USLE factors in East Shewa zone is presented below (Fig. 9). The estimated soil erosion was classified into six different erosion severity classes : slight erosion is 0–5 t ha^{-1} yr^{-1}, moderate is 5–10 t ha^{-1} yr^{-1}, high is 10–20 t ha^{-1} yr^{-1}, very high is 20–40 t ha^{-1} yr^{-1}, severe is 40–80 t ha^{-1} yr^{-1}, very severe is $>$80 t ha^{-1} yr^{-1}. We obtained the map below.

The area of damage or the eroded area represents almost 82% of to the total area of East Shewa as illustrated in Fig. 10.

The result of the erosion study indicates -as shown in the map of spatial distribution of soil loss- that :

—22.3% of the total area is under very high erosion, comprising between 20 to 40 t ha^{-1} yr^{-1}

—The potential of erosion under very severe class

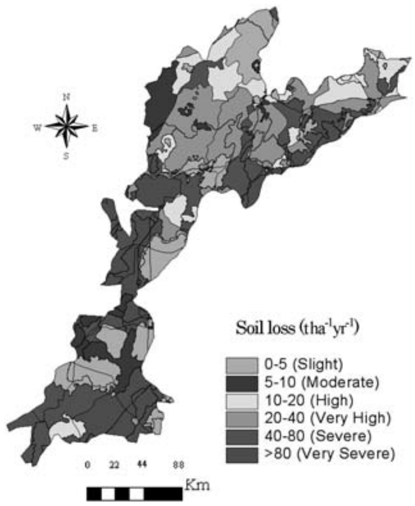

Fig. 9 Spatial distribution of soil loss in East Shewa

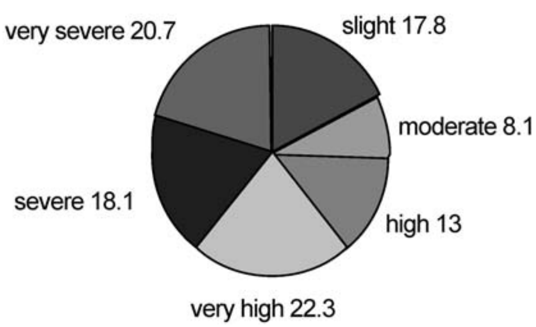

Fig. 10 Area distribution of erosion risk (%)

defined with an amount of erosion beyond 80 t ha^{-1} yr^{-1} and occupying 20.7% of the total study area.

—Severe erosion corresponding to an amount of soil loss between 40 and 80 t ha^{-1} yr^{-1} is occupying 18.1% of the area.

If we observe both maps of rainfall erosivity and soil loss spatial distribution, we note that the zones where rainfall erosivity is high the erosion is severe to very severe. From the land cover map and soil loss map, we note that shrubland and cultivation zones correspond to the high, very high, severe and very severe soil loss. Accordingly, high erosion classes concentrate in areas where land is used for field crops with feeble conservation activities.

These areas are notably located in the center and south, and are covered mainly by cultivation. Thus we concluded that croplands are most prone to erosion because they are tilled repetitively and left without vegetation cover. Besides, natural forests, plantation and woodland correspond to the lowest area prone to erosion because plant cover protects the soil from the erosive power of runoff and rain drops.

These eroded areas correspond also to the highest values of the LS which relates the severity of soil erosion with the steepness and length of the slope. Table 1 shows the evidence that large areas which are prone to severe to very severe erosion are located on moderate and steep slopes. These areas range between 27 to 34.6% of the total area of East Shewa.

Table 1 Area distribution across slope and erosion (%)

	Slope Classes		
Erosion Classes	*gentle*	*moderate*	*steep*
slight	16.9	16.2	23.7
moderate	1.1	2.5	13.1
high	27.4	5.6	4.7
very high	46.3	16.6	0.3
severe	7.1	27.1	23.5
very severe	1.2	32.1	34.6
total	100	100	100

4. Conclusion and perspectives

It has been attested that Ethiopia has a lonf history of soil erosion. The results of this study confirm this statement. In fact, we may affirm the critical situation of degradation in East Shewa. Actually, we observed that rainfall erosivity, soil erodibility, land-cover management factor and topography factor have high values in areas located essentially in the north-east, center and south-east of East Shewa which reflects the most erodible soil locality prone to degradation.

Hence, according to the obtained results, we concluded that 82% of the lands in East Shewa zone are under high, very high, severe and very severe erosion and located in the north-eastern, central and southern parts of the study site and are covered mainly with cultivation, shrubland and grassland. This is the evidence for erosive areas repeatedly cultivated or frequently used for grazing such shrublands and grasslands.

This study is valuable as a step to further research on the relationship between environmental and socioeconomic conditions and to illustrate the efficiency of conservation techniques at both levels.

Still, there is a need to confirm and validate the results of USLE prediction with direct field measurements of soil erosion on farmland. For that reason, previous measures were accomplished in order to assess soil loss at a small scale at the visited farmlands of Dalecha Gada village in Boset Wareda (North East Shewa).

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This work would have not been completed without the contribution of many individuals and institutions, among them Dr. MUHAMMAD AQIL (Post-Doctoral fellow at Tokyo University of Agriculture) to whom we express our deep gratitude and to the Ministry of Agriculture of Ethiopia for the valuable data provided to us.

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USLE を用いたエチオピア国東ショワ地域における土壌侵食の評価

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（平成 22 年 2 月 25 日受付/平成 23 年 1 月 21 日受理）

要約：エチオピア国では山林の伐採および耕作区域の拡大のため，土壌侵食による国土の荒廃が著しく，人々の生活を脅かす深刻な問題となっている。実際に，土壌侵食に伴う土壌栄養分の減少，干ばつおよび飢饉がエチオピアで頻繁に起こっている。生産性の高い表土のほとんどは侵食作用で削り取られ，結果として慢性の食糧不足および回復の困難な貧困がつづいている。土壌侵食は，エチオピア国において農業の持続性を脅かす重要な環境問題である。

本研究の目的は，エチオピア国オロミア地域の東ショワ地帯を対象として，土壌流亡予測式（USLE）と地理情報システム（GIS）を統合することにより，広域的な土壌侵食の危険性を明らかにすることである。降雨量，地形，土壌および土地利用データを USGS およびエチオピア政府から入手し，GIS を使用して広域データベースを作成した。その結果，侵食の程度が高い，非常に高い，著しい，非常に著しいと分類された面積が対象地域の 74 %に上ることが明らかになった。それらの地域は北東地域，中央部及びと南部に分布し，主に耕作が繰り返されている土地や，家畜の放牧にさらされる潅木地と草原であった。

キーワード：土壌侵食，土地被覆，GIS，USLE，エチオピア

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